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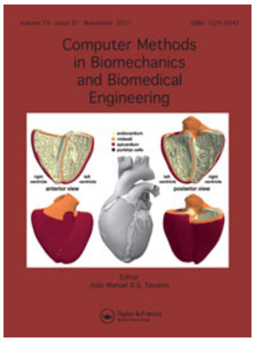

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Load sharing during team lifting

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1. Introduction

The industrial revolution is under permanent development, and it is closely tied to technological advancements. A smooth transition from Industry 3.0 Automation, Industry 4.0 Collaboration to Industry

5.0 Human-Robot Co-working is taking place (Demir et al. 2019). These new concepts take advantage of both human and robotic intelligence to create a genuine symbiosis. However, the teamwork achieved should continuously be adapted to the real need of the human in order to behave accordingly.

As a means to comply with all human motion skills, a CoBot behavior should be inspired by those of humans: in other words Biomimetic.

When it comes to Human-Robot lifting tasks, CoBot behaves accordingly to pre-modeled optimized policy inspired by human lifting strategies (El Zaatari et al. 2019). Hence, to improve the performance and adaptability of the Human-Robot Co-working, it is essential to highlight the various aspect of a Human-Human lifting task.

Most of the research that studied team lifting, described either the impact of a team-lifting task on the lifting strength efficiency (Karwowski 1988) or on the energetic cost of the movement (Fumery et al. 2021). Nevertheless, there is a need to understand the sharing strategies among team members. The aim of this study is to analysis the coordination of the forces exerted on the handles of a device transported by a pair of volunteers. We hypothesized that during the performance of this task, a controlateral force synchronization may take place.

2. Methods

2.1. Experimental tasks

Six pairs of healthy females and four pairs of healthy males participated in this study (Table 1). Each gender groups were paired by heights and weights. Each pair of volunteers performed three trials in two different conditions. They were asked to transport a table-like object over a distance of 8 m (Figure 2). The only instructions given were to look in the same

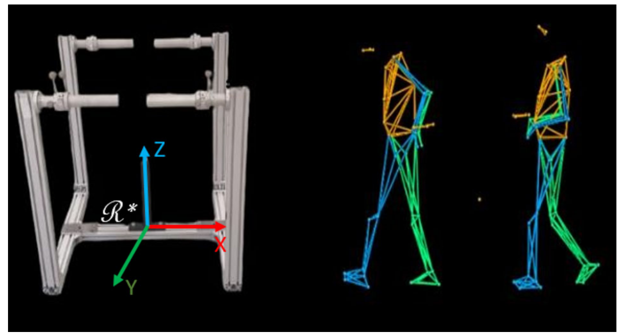

Figure 1. (Left) the Table-like device equipped with 4 handles each including a 6 axis force sensor, (Right) Subject 1, in the front, and Subject 2, in the back, carrying the device.

Table 1. Anthropometric description of the sample

Gender	Age (Y)	Height (cm)	Weight (kg)	Arm Span (cm)
Female (n = 12)	23.8 ± 1.9	165 ± 5.9	61 ± 5.3	169.2 ± 6.6
Male (n = 8)	25.6 ± 3.3	178 ± 5.2	70.3 ± 7.8	183.1 ± 5.3

direction and to carry the device with a hand supination.

S1 was in the front of the device with his arms behind his back, and S2 was behind the device with his arms in font of him (Figure 1). The Control Condition (CC) and the Loaded Condition (LC) consisted in transporting the same device free of load (m = 24,4 kg) then loaded by 33% of the subject's total body mass, respectively. The trials were performed randomly at a free chosen walking speed.

2.2. Data recording

A Vicon motion capture system of 20 cameras enabled us to record the displacement of each subject and to detect the beginning and the end of a complete gait cycle. The table-like device was equipped of four force sensors (Sensix©, France) that recorded the forces exerted on X, Y, and Z axis expressed in R^* and sampled at 1000 Hz (Figure 1).

2.3. Statistical analysis

The forces recordings were expressed in the global coordinate system taking into account the cardanic angles. The Percentage of Exerted Forces (PEF) has been computed to evaluate the load sharing in each axis and for each subject during CC and LC over a complete gait cycle as follow:

$$PEF = \frac{EF_M}{EF_T}.100$$

with EF_M, the external mean force exerted on the handle by one subject, and EF_T, the sum of the external forces norms exerted by both subjects on the handles. Matlab R2019b© was used for data computation

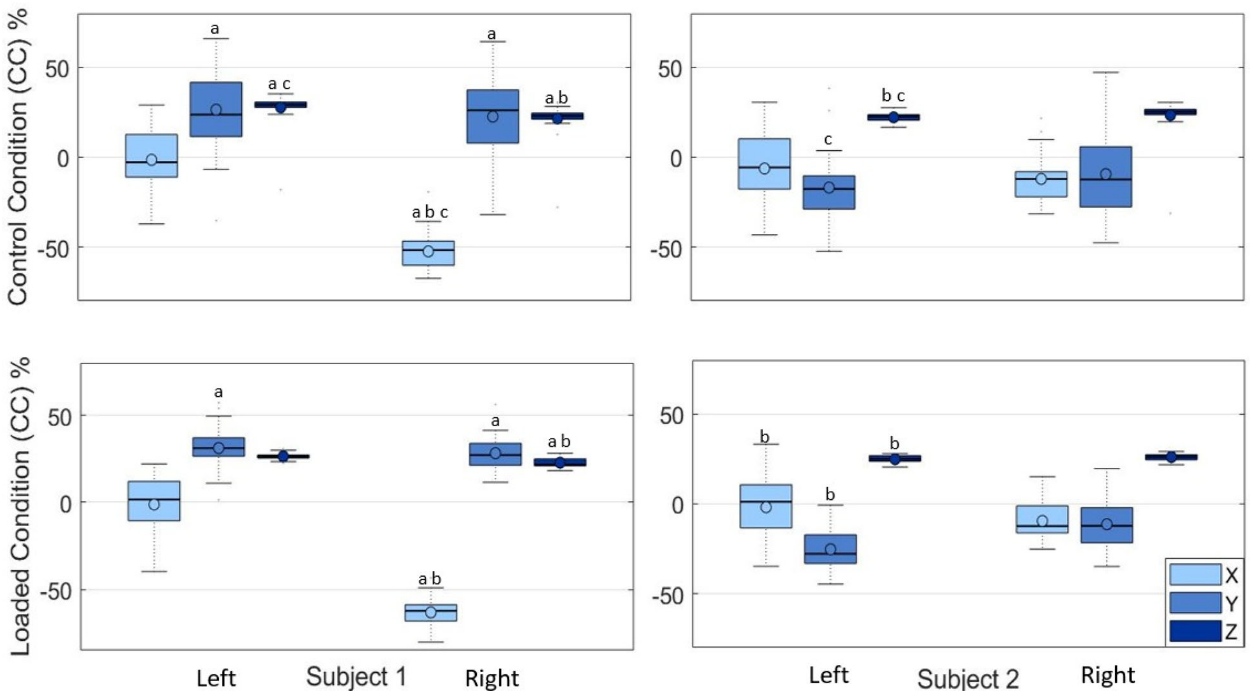

Figure 2. PEF in R^* Forces distribution during a collective load transport. a, b, and c, statistically significant differences across S1 and S2, right and left hand of the same subject, and CC *vs* LC, respectively ($p < 0.005$).

and statistical analysis. Due to the non-homogeneity of the data, a Wilcoxon test has been chosen to compare right, and left hands, S1 and S2 and CC to LC. The significance threshold was set to 0.005.

3. Results and discussion

The analysis focused on the individual PEF implication of the subjects during the transport of the device (Figure 2). This implication corresponds to the X, Y, and Z forces exerted on R^*.When comparing the right to the left hand in CC, the forces exerted on the mediolateral axis X by subject 1 (S1) were different, unlike subject 2 who were equally distributed with its left and right hands. The plausible explanation of these results is the initial position. Indeed, S1 carried the device with his hand behind his back with an imposed supination grasping. This position induced a decrease of the arms freedom degree and the capacity to control the force distribution along the X-axis. Notwithstanding, the right hand of S1 may have guide the device. Along Y-axis, no difference appeared across the right and left hand in S1 or S2 but the PEFy of S1 and S2 were of the same range BUT of opposite signs. This distribution is in accordance with the controls of the forward acceleration and of the rotation of the table-like device around the vertical axis. Finally, along the vertical Z-axis, the PEFz of the right and left hands of both subjects were significantly different. Nevertheless, the average PEFz was by 20 to 30 % and of the same sign, which indicates a sharing of the vertical constraint due to the weight.

Globally, the same strategy was used during the LC, while the PEF was balanced between the right and the left hand of the subjects. The single difference due to the increase of the load concerned the PEFz of the left hand and revealed a better sharing of the higher load according to the results of Fumery et al. (2021).

4. Conclusions

This study reveals a collaborative strategy of the two subjects implied in a carrying task. They shared the weight along the vertical axis, in the same way, controlling also the roll of the device. This result highlighted a contralateral coordination between S1 and S2 on the anteroposterior direction. Allowing a parallel control of the forward acceleration and the yaw of the device. These strategies could be reproduced to improve CoBot adaptability.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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